GEOGRAPHICAL REPORTS
OF TOKYO METROPOLITAN UNIVERSITY 52 (2017) 1–9

EFFECT OF SPATIAL RESOLUTION ON SIMULATED RAINFALL OVER WESTERN PHILIPPINES

Julie Mae B. DADO and Hiroshi G. TAKAHASHI

Abstract This study evaluated the reproducibility of simulated rainfall over western Philippines at different resolutions using a regional climate model, Advanced Research Weather Research and Forecasting Model (WRF-ARW). Four sets of experiments with distinct horizontal mesh sizes of 25, 12.5, 8 and 5 km were done for the summer monsoon period of June to August over 31 years from 1982 to 2012. The spatial distribution of monthly rainfall amount improved for higher resolution simulations. The experiment run at 12.5 km was able to reproduce monthly rainfall distribution closest to observed rainfall. The domains of 8-km and 5-km resolutions, which were further downscaled from a coarser initial domain, performed better in capturing the monthly rainfall distribution than the 25 km-single domain setup. In addition, high rainfall amount was simulated over an offshore area apart from the coastline in the windward direction of the Asian summer monsoon westerlies. This offshore rainfall was also observed in other regions of the monsoon Asia.

Key words: summer monsoon, rainfall, numerical simulation, resolution dependency

1. Introduction

Regional climate models (RCMs) were initially developed to compensate for the coarseness limitation of global climate models (GCMs), allowing for better representation of orographic forcing which is known to play a major role in mesoscale processes (Doyle 1997). The progressive increase of available computing power in recent years has allowed models to be run at higher horizontal and vertical resolutions thus improving the representation of topography, land cover and small-scale processes that are normally difficult to simulate in coarser model experiments. A recent 14-km GCM conducted 20-year-long climatological experiments using the world's fastest computer (Kodama *et al.* 2015). This kind of simulation, however, is still very limited in terms of accessibility. Thus RCM remains to be an important option for high-resolution numerical experiments in climate science.

Various sensitivity studies showed the impact of horizontal resolution in simulating rainfall. For instance the distribution of rainfall in North America was better reproduced at higher model grid resolution (Xue *et al.* 2007). The spatial distribution of monthly precipitation over Asian monsoon regions was also better simulated at higher resolutions without convective parameterization (Takahashi *et al.* 2009; Takahashi *et al*. 2010a; Takahashi *et al.* 2015; Sugimoto and Takahashi 2016, Sugimoto and Takahashi 2017; Dado and Takahashi 2017). It has also been shown that 24-h rainfall forecasts in India improved when WRF model resolution is increased (Kumar *et al.* 2016).

The western region of the Philippines receives most of its rainfall during the Asian summer monsoon months. This rainfall is essential as a water source but it is also a perennial cause of destructive flooding in the region. The large-scale atmospheric condition during the summer monsoon provides a conducive environment for convective activity. In addition, the western Philippines has a complex topography, which further enhances convective processes.

One of the challenges in simulating rainfall in this region hinges on the fact that the country has limited computational resources. It is thus necessary to study the sensitivity of summer monsoon rainfall over western Philippines to various horizontal resolutions. Determining the sufficient resolution at which monsoon rainfall can be reproduced by the model will thus provide for efficient and reliable information regarding monsoon rainfall.

2. Model and experimental setup

We used a nonhydrostatic regional climate model, Advanced Research Weather Forecasting Model (WRF) version 3.6.1 with the Advanced Research WRF dynamical core (Skamarock *et al.* 2008), to assess simulated rainfall across different spatial resolutions. In particular, we compare experiments run with horizontal mesh sizes of 25, 12.5, 8 and 5 km. The domains less than 10 km resolution are nested (two-way feedback) within a coarser domain of 40 and 25 km, respectively. The model domain and setup is shown in Fig. 1.

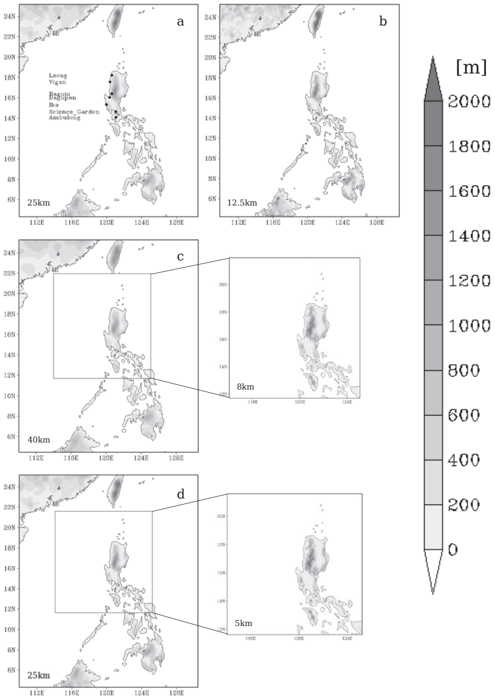


Fig. 1 Topographical map of the study area showing the different domains used in the experiments - (a) 25 km, (b) 12.5 km, (c) 8 km and (d) 5 km. Domains (c) and (d) were nested within coarser resolution domains, each noted in the figure. The black points in (a) shows the location of the seven observation stations from which simulated monthly rainfall are evaluated in terms of spatial distribution.

The simulation period is from May 27 to September 1 of each year from 1982 to 2012 for all experiments. Multiyear simulations were done to investigate the robustness of the model under various atmospheric conditions. The first five days serve as the simulation spin up time and the analysis was focused on the summer monsoon rainfall months of June to August. All domains have 30 terrain-following levels. No cumulus convective parameterization (CCP) scheme was applied in order to assess the effect of spatial resolution alone. The following physics schemes were used WSM 6-class graupel microphysics scheme (Hong and Lim 2006), Mellor-Yamada-Janjic planetary boundary layer scheme (Janjić 1994), and the Unified NOAH land surface scheme (Tewari *et al.* 2004).

The initial and lateral boundary conditions were from the ERA-Interim (Berrisford *et al.* 2009) of the European Centre for Medium-Range Weather Forecasts (ECMWF) and SST from the Optimum Interpolation Sea Surface Temperature (OISST) version 2 (Reynolds *et al.* 2002), with the monthly value of the SST being prescribed every six hours.

Simulated rainfall are evaluated using data from the Asian Precipitation - Highly-Resolved Observational Data Integration Towards Evaluation (APHRODITE) of Water Resources (Yatagai *et al.* 2012) and Tropical Rainfall Measuring Mission (TRMM) - Precipitation Radar (PR). We also used select stations of the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA). These seven (7) stations, shown as black points in Fig. 1a, span the western part of the Philippines and experience summer monsoon rainfall from June to August.

3. Results

Spatial distribution of monthly rainfall

The spatial pattern of the simulated rainfall was evaluated by comparing the climatological monthly total with the APHRODITE dataset (Fig. 2). Since APHRODITE has data until 2007, we averaged the monthly total rainfall from 1982–2007 in producing these maps.

Figure 2 shows the climatological rainfall distribution for June, July and August for APHRODITE and for the experiments at different horizontal resolutions. There is an overestimation of simulated rainfall at all resolutions when compared with APHRODITE, especially in areas of high elevation. This may represent a positive bias of the simulated rainfall over high-elevation regions. In addition, the APHRODITE data were mostly obtained from coastal observation stations, resulting in another bias.

The rainfall distribution at 8-km and 5-km resolutions shows a strong boundary effect in the southern region over the ocean. This rainfall is considered as a model artifact due to further downscaling and may not represent real rainfall values.

Although, the model consistently overestimates the rainfall for all resolutions, it is worth noting that the structure of spatial rainfall is better produced in the higher resolution models, especially the coastal rainfall on the western section.

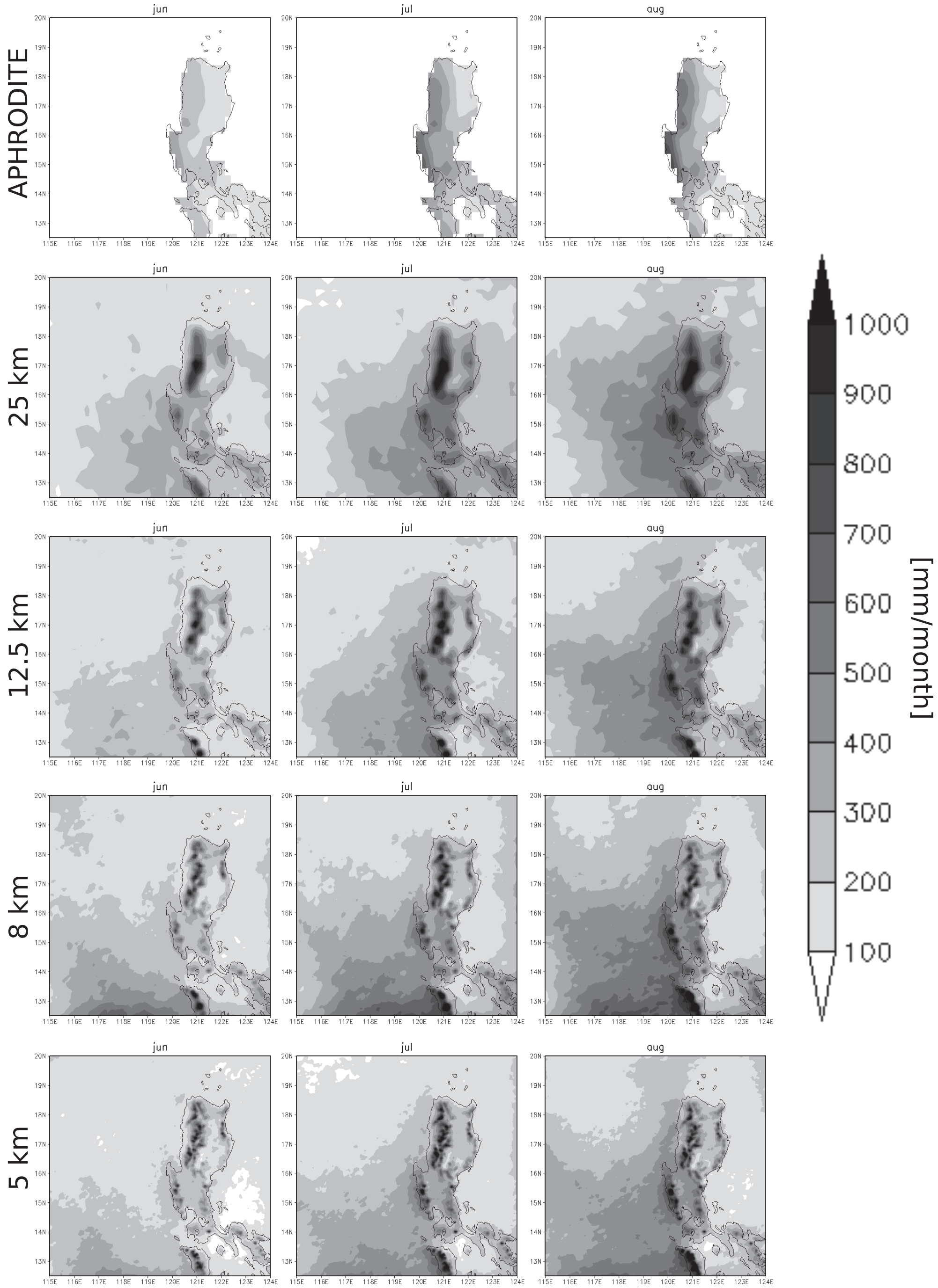


Fig. 2 Climatological monthly rainfall (mm month^{-1}) for APHRODITE and model simulations at different resolutions noted in the figure, for the years 1982–2007.

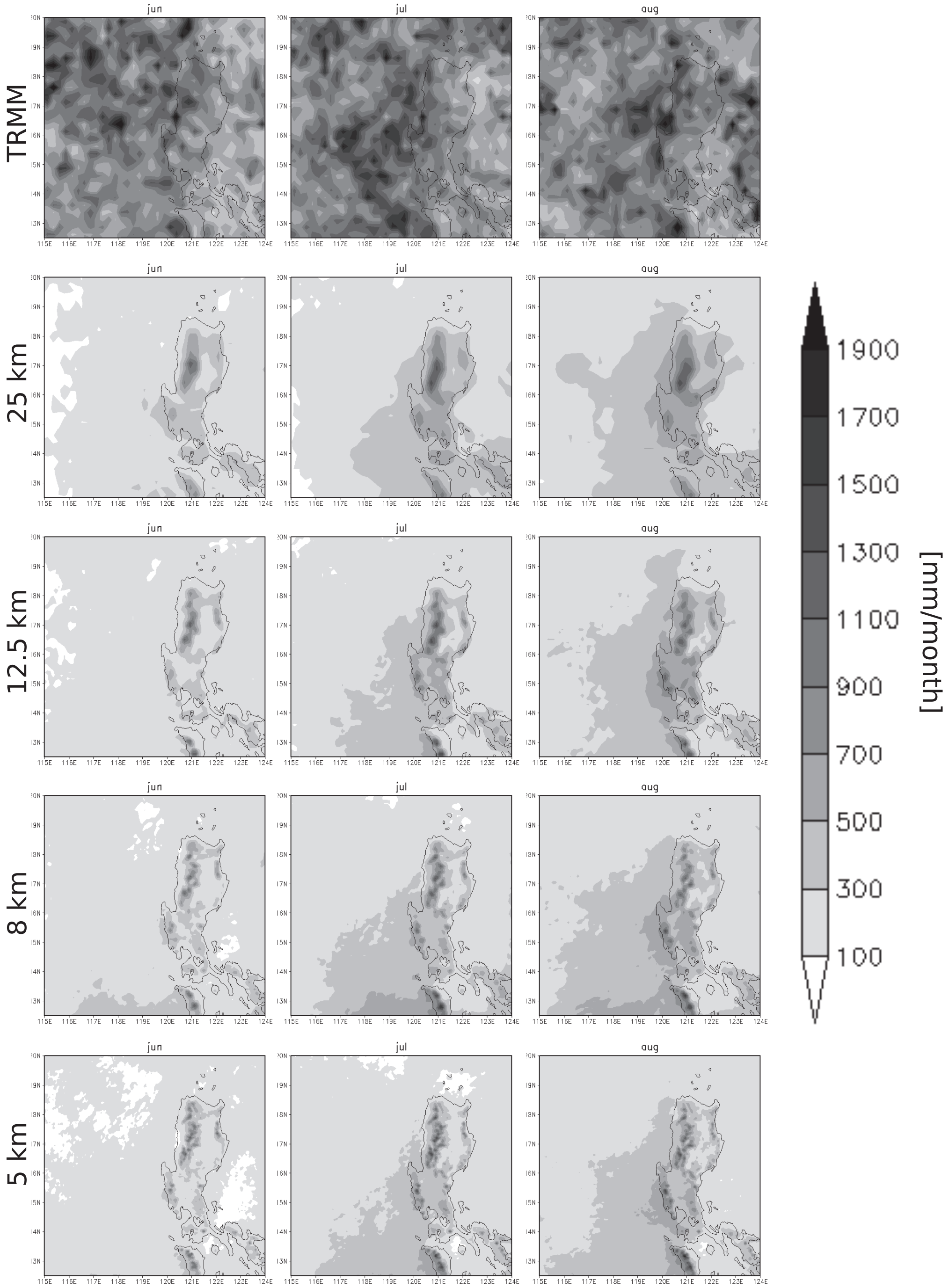


Fig. 3 Climatological monthly rainfall (mm month^{-1}) for TRMM and model simulations at different resolutions noted in the figure, for the years 1998–2012.

We confirm this coastal rainfall structure by comparing the model result with another gridded rainfall dataset, TRMM-PR (Fig. 3). For these maps, we again averaged the monthly total rainfall from 1998–2012 to be consistent with TRMM-PR's available data. The model, this time, underestimated the rainfall compared to TRMM-PR. However, the coastal rainfall is better produced in the higher resolution models along with the oceanic rainfall to the west of the Philippines.

This high rainfall over an offshore area apart from the coastline in the windward direction of the Asian monsoon westerlies was similar to the observed high rainfall over west of the Indochina Peninsula (Takahashi *et al*. 2010b), west of the Indian subcontinent and the Maritime continent (Mori *et al.* 2004). The mechanism of the high rainfall amount west of the Philippines can be similar to that of the other regions, although characteristics of the atmospheric circulation over the Maritime Continent may be very different. In order to simulate the offshore rainfall over the Asian monsoon region using a climate model, high resolution without convective parameterization can be a necessary condition. Further studies on the offshore rainfall over the Asian monsoon regions are required.

Quantifying model skill

We assess the ability of the model in reproducing spatial variability of monthly rainfall by comparing it with observed data from select PAGASA stations, shown as black points in Fig. 1a.

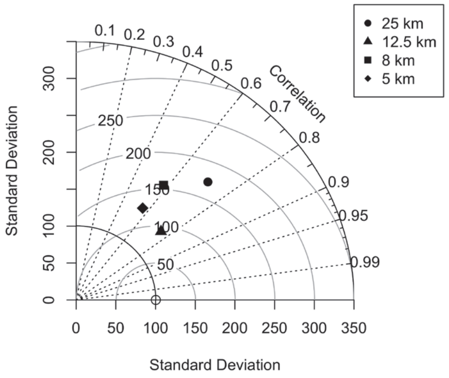
We calculated the correlation coefficient, standard deviation and centered root-mean-square (RMS) difference between the observed and simulated rainfall. Specifically, the climatological rainfall value of the nearest model grid point to the station is compared to the climatological rainfall from the observation station. The skill of the model relative to observed data is summarized as a Taylor diagram (Taylor 2001) for each month in Fig. 4. The model agrees well with observation if it lies nearest the point marked as an open circle along the x-axis of the Taylor diagram.

Figure 4 shows the value of the standard deviation increasing from June to August suggesting larger variation among stations for higher rainfall months. The standard deviation of the observed data is shown as a radial arc from the origin in the Taylor diagram and any model lying along this arc captures the amplitude of variation of the observation.

The single domain 12.5-km simulation performs best among the four experiments for all months. This shows that at 12.5-km resolution, WRF is already able to capture the monthly distribution of rainfall close to observed data.

The nested domains at 8 km and 5 km perform better than the coarsest model at 25 km. This suggests that further downscaling improves the model's skill in capturing monthly rainfall distribution by minimizing the centered RMS difference improving the model's spatial variation of rainfall.

(a) jun



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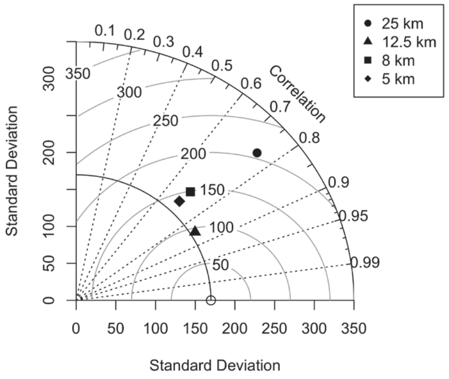

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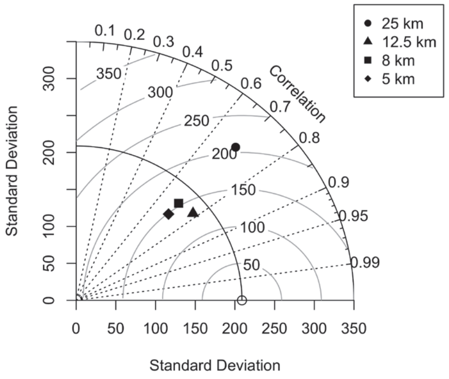

Fig. 4 Taylor diagram showing the spatial distribution of the 31-year-mean monthly rainfall over the western Philippines using data from seven PAGASA stations shown in Fig. 1a.
The values from the model are obtained from the nearest grid point of the station location.

4. Conclusions

The performance of the WRF model in simulating the monthly summer monsoon rainfall over western Philippines was evaluated in experiments using four spatial resolutions. The rainfall values in the model were higher when compared to APHRODITE, but lower when compared to TRMM data. This difference in rainfall values may be due to model bias (i.e. model producing higher rainfall in areas of high elevation) or observed dataset bias. Although the model was not able to capture the rainfall amount, it was able to show better spatial distribution of rainfall at higher resolutions, especially for coastal and oceanic rainfall on the western part of the Philippines.

The single domain model at 12.5 km performs best among the four sets of experiment. It was able to produce monthly rainfall distribution closest to the observed station data using metrics represented in a Taylor diagram. This suggests that at 12.5 km, WRF is already able to capture the distribution of summer monsoon rainfall over western Philippines. In addition, further downscaling a coarse domain run improved the ability of the model to capture rainfall distribution in this area.

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